May 10th, 1860.

Sir BENJAMIN C. BRODIE, Bart., President, in the Chair.

The following Gentlemen were proposed by the Council for Election as Foreign Members, and it was announced that they would be balloted for at the ensuing Meeting of the Society, viz.—

Alexander Dallas Bache.
Hermann Helmholtz.
Albert Kölliker.
Philippe Edouard Poulletier de Verneuil.

The Bakerian Lecture was then delivered by Mr. Fairbairn, F.R.S.

The Lecturer gave a condensed exposition of the experiments and results detailed in the following Paper. He also exhibited the apparatus employed, and explained the methods followed.

"Experimental Researches to determine the Density of Steam at all Temperatures, and to determine the Law of Expansion of Superheated Steam." By WILLIAM FAIRBAIRN, Esq., F.R.S., and THOMAS TATE, Esq.

(Abstract.)

The object of these researches is to determine by direct experiment the law of the density and expansion of steam at all temperatures. Dumas determined the density of steam at 212° Fahr., but at this temperature only. Gay-Lussac and other physicists have deduced the density at other temperatures by a theoretical formula true for a perfect gas:

$$\frac{VP}{V_1P_1}=\frac{459+T}{459+T_1}. \quad \ldots \ldots \quad (1.)$$

On the expansion of superheated steam, the only experiments are those of Mr. Siemens, which give a rate of expansion extremely high, and physicists have in this case also generally assumed the rate of expansion of a perfect gas. Experimentalists have for some time questioned the truth of these gaseous formulæ in the case of condensable vapours, and have proposed new formulæ derived from the dynamic theory of heat; but up to the present time no *reliable direct*

experiments have been made to determine either of the points at issue. The authors have sought to supply the want of data on these questions by researches on the density of steam upon a new and original method.

The general features of this method consist in vaporizing a known weight of water in a globe of about 70 cubic inches capacity, and devoid of air, and observing by means of a "*saturation gauge*" the exact temperature at which the whole of the water is converted into steam. The saturation gauge, in which the novelty of the experiment consists, is essentially a double mercury column balanced upon one side by the pressure of the steam produced from the weighed portion of water, and on the other by constantly saturated steam of the same temperature. Hence when heat is applied the mercury columns remain at the same level up to the point at which the weighed portion of water is wholly vaporized; from this point the columns indicate, by a difference of level, that the steam in the globe is superheating; for superheated steam increases in pressure at a far lower rate than saturated steam for equal increments of temperature. By continuing the process, and carefully measuring the difference of level of the columns, data are obtained for estimating the rate of expansion of superheated steam.

The apparatus for experiments at pressures of from 15 to 70 lbs. per square inch, consisted chiefly of a glass globe for the reception of the weighed portion of water, drawn out into a tube about 32 inches long. The globe was enclosed in a copper boiler, forming a steam-bath by which it could be uniformly heated. The copper steam-bath was prolonged downwards by a glass tube enclosing the globe stem. To heat this tube uniformly with the steam-bath, an outer oil-bath of blown glass was employed, heated like the copper bath by gas jets. The temperatures were observed by thermometers exposed naked in the steam, but corrected for pressure. The two mercury columns forming the saturation gauge were formed in the globe stem, and between this and the outer glass tube; so long as the steam in the glass globe continued in a state of saturation, the inner column in the globe stem remained stationary, at nearly the same level as that in the outer tube. But when, in raising the temperature, the whole of the water in the globe had been evaporated and the steam had become superheated, the pressure no longer balanced that in

the outer steam-bath, and, in consequence, the column in the globe stem rose, and that in the outer tube fell, the difference of level forming a measure of the expansion of the steam. Observations of the levels of the columns were made by means of a cathetometer at different temperatures, up to 10° or 20° above the saturation point; and the maximum temperature of saturation was, for reasons developed by the experiments, deduced from a point at which the steam was decidedly superheated.

The results of the experiments, which in the paper are given in detail, show that the density of saturated steam at all temperatures, above as well as below 212°, is invariably greater than that derived from the gaseous laws.

The apparatus for the experiments at pressures below that of the atmosphere was considerably modified; and the condition of the steam was determined by comparing the column which it supported with that of a barometer. The results of these experiments, reduced in the same way, are extremely consistent.

As the authors propose to extend their experiments to steam of a very high pressure, and to institute a distinct series on the law of expansion of superheated steam, they have not at present given any elaborate generalizations of their results. The following formulæ, however, represent the relations of specific volume and pressure of saturated steam, as determined in their experiments, with much exactness.

Let V be the specific volume of saturated steam, at the pressure P, measured by a column of mercury in inches; then

$$V=25{\cdot}62+\frac{49513}{P+{\cdot}72}. \qquad (2.)$$

$$P=\frac{49513}{V-25{\cdot}62}-0{\cdot}72. \qquad (3.)$$

In regard to the rate of expansion of superheated steam, the experiments distinctly show that, for temperatures within about ten degrees of the saturation point, the rate of expansion greatly exceeds that of air, whereas at higher temperatures the rate of expansion approaches very near that of air. Thus in experiment 6, in which the maximum temperature of saturation is 174°·92, the coefficient of expansion between 174°·92 and 180° is $\frac{1}{190}$, or three times that of air; whereas between 180° and 200° the coefficient is very nearly the

same as that of air (steam $=\frac{1}{637}$, air $=\frac{1}{639}$), and so on in other cases. The mean coefficient of expansion at zero of temperature from seven experiments below the pressure of the atmosphere, and calculated from a point several degrees above that of saturation, is $\frac{1}{438}$, whereas for air it is $\frac{1}{459}$. Hence it would appear that for some degrees above the saturation point the steam is not decidedly in an aëriform state, or, in other words, that it is watery, containing floating vesicles of unvaporized water.

Table of Results, showing the relation of density, pressure, and temperature of saturated steam.

Number of Exper.	Pressure in lbs. per sq. in.	Pressure in inches of mercury.	Max. temp. of saturation, Fahr.	Specific Volume. From experiment.	Specific Volume. By formula (2).	Proportional error of formula (2).
1	2·6	5·35	136°·77	8266	8183	$+\frac{1}{100}$
2	4·3	8·62	155·33	5326	5326	0
3	4·7	9·45	159·36	4914	4900	$-\frac{1}{350}$
4	6·2	12·47	170·92	3717	3766	$+\frac{1}{74}$
5	6·3	12·61	171·48	3710	3740	$+\frac{1}{123}$
6	6·8	13·62	174·92	3433	3478	$+\frac{1}{76}$
7	8·0	16·01	182·30	3046	2985	$-\frac{1}{50}$
8	9·1	18·36	188·30	2620	2620	0
9	11·3	22·88	198·78	2146	2124	$-\frac{1}{97}$
1′	26·5	53·61	242·90	941	937	$-\frac{1}{235}$
2′	27·4	55·52	244·82	906	906	0
3′	27·6	55·89	245·22	891	900	$+\frac{1}{100}$
4′	33·1	66·84	255·50	758	758	0
5′	37·8	76·20	263·14	648	669	$+\frac{1}{32}$
6′	40·3	81·53	267·21	634	628	$-\frac{1}{100}$
7′	41·7	84·20	269·20	604	608	$+\frac{1}{150}$
8′	45·7	92·23	274·76	583	562	$-\frac{1}{29}$
9′	49·4	99·60	279·42	514	519	$+\frac{1}{100}$
11′	51·7	104·54	282·58	496	496	0
12′	55·9	112·78	287·25	457	461	$+\frac{1}{114}$
13′	60·6	122·25	292·53	432	428	$-\frac{1}{108}$
14′	56·7	114·25	288·25	448	456	$+\frac{1}{56}$

Adopting the notation previously employed, and putting r for the rate or coefficient of expansion of an elastic fluid at t_1 temperature, we find

$$r=\frac{1}{\epsilon_1+t_1}=\frac{\frac{V_2 p_2}{V_1 p_1}-1}{t_2-t_1}, \quad \ldots \ldots \quad (4.)$$

where $\frac{1}{\epsilon_1}=$ the rate of expansion at zero of temperature. In the case of air $\epsilon_1=459$.

The following Table gives the value of the coefficient of expansion

of superheated steam taken at different intervals of temperature from the maximum temperature of saturation.

Number of the Exper.	Max. temp. of saturation.	Temperatures between which the expansion is taken.		Coefficient of expansion of superheated steam.	Coefficient of expansion of air.
1	136°·77	140°	170°	$\frac{1}{593}$	$\frac{1}{599}$
2	155·33	160	190	$\frac{1}{556}$	$\frac{1}{619}$
3	159·36	159·36	170·2	$\frac{1}{150}$	$\frac{1}{618}$
		170·2	209·9	$\frac{1}{624}$	$\frac{1}{629}$
5	171·48	171·48	180	$\frac{1}{200}$	$\frac{1}{630}$
		180	200	$\frac{1}{604}$	$\frac{1}{639}$
6	174·92	174·92	180	$\frac{1}{190}$	$\frac{1}{634}$
		180	200	$\frac{1}{637}$	$\frac{1}{639}$
7	182·30	182·3	186	$\frac{1}{230}$	$\frac{1}{641}$
		186	209·5	$\frac{1}{630}$	$\frac{1}{645}$
8	188·30	191	211	$\frac{1}{604}$	$\frac{1}{650}$
1′	242·9	243	249	$\frac{1}{517}$	$\frac{1}{702}$
4′	255·5	257	259	$\frac{1}{392}$	$\frac{1}{716}$
		257	264	$\frac{1}{600}$	$\frac{1}{716}$
6′	267·21	268	271	$\frac{1}{210}$	$\frac{1}{727}$
		271	279	$\frac{1}{640}$	$\frac{1}{730}$
7′	269·2	271	273	$\frac{1}{232}$	$\frac{1}{730}$
		273	279	$\frac{1}{551}$	$\frac{1}{733}$
9′	279·42	283	285	$\frac{1}{298}$	$\frac{1}{742}$
		285	289	$\frac{1}{533}$	$\frac{1}{744}$
13′	292·53	297	299	$\frac{1}{281}$	$\frac{1}{756}$
		299	302	$\frac{1}{638}$	$\frac{1}{758}$

Hence it appears, that as the steam becomes more and more superheated, the coefficient of expansion approaches that of a perfect gas. The authors hope that these experiments may be continued, and that the results obtained at greatly increased pressures will prove as important as those already arrived at.

May 24, 1860.

Sir BENJAMIN C. BRODIE, Bart., President, in the Chair.

In accordance with Notice given at the last Meeting, the Right Hon. Earl de Grey and Ripon was proposed for election and immediate ballot; and the ballot having been taken, his Lordship was declared duly elected.

Alexander Dallas Bache, Hermann Helmholtz, Albert Kölliker, and Philippe Edouard Poulletier de Verneuil were severally balloted for, and declared duly elected Foreign Members of the Society.